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ABSTRACT

This paper describes the development of pedagogical content knowledge (PCK) in secondary chemistry and physics preservice teachers. Teacher beliefs are intricately tied to how they make decisions for implementing instructional strategies, and those beliefs aid in the development of pedagogical content knowledge. A model for pedagogical content knowledge development was constructed to include teacher beliefs as an important aspect of the "learning to teach" locution. Four female prospective teachers participated in the study. The data collection procedure included structured and semi-structured interviews, and the microgenetic method was used for observation of the development of pedagogical content knowledge. (Contains 93 references.) (YDS)

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The TTF Model to Explain PCK in Teacher Development

by
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The TTF Model to Explain PCK in Teacher Development

Introduction

Many colleges and universities nationwide are engaged in revising their pre-service teacher education programs. They are using current research on effective teaching to guide their decision making. Two areas of research that have influenced teacher education development are teacher beliefs and teacher knowledge bases. Separately, these topics have indirectly influenced teacher education programs. Together, these topics combine to form a formidable base for teacher development and "learning to teach." One of the most difficult aspects of "learning to teach" is making the transition from personal beliefs about content to thinking about how to organize and represent the content of a discipline in ways that will facilitate student understanding. Without proper instructional guidance or models of teaching, prospective teachers will spend much of their time learning content, rather than "thinking about how to present content in a way that will facilitate student understanding" (Borko, 1989, p. 81).

The purpose of this study was to describe how pedagogical content knowledge (PCK) developed in prospective secondary chemistry and physics teachers. Beliefs were intricately tied to how students made decisions for implementing instructional strategies and how the beliefs aided in the development of PCK. A model for PCK development was constructed to include teacher beliefs as an important aspect of the proverbial "learning to teach" locution.

Literature Review

Pedagogical Content Knowledge

Pedagogical content knowledge was first proposed by Shulman (1986) and developed with colleagues in the *Knowledge Growth in Teaching* project (e.g., Grossman, 1987; Shulman, 1986; Shulman & Grossman, 1988; Wilson, Shulman, & Richert, 1987). The *Knowledge Growth in Teaching* project studied how novice teachers acquired new understandings of their content for the purposes of teaching it, and how these new understandings influenced their teaching. Shulman wrote that PCK included "an understanding of how particular topics, problems, or issues are organized, presented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (1987, p. 8). The research that has stemmed from the introduction of the term PCK has addressed the question of how students learn to teach subjects that they already know or are in the process of acquiring (Geddis, 1993; Grossman,

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1990; Grossman, Wilson, & Shulman, 1989; Gudmundsdottir, 1987; Magnusson, Borko, & Krajcik, 1994; Marks, 1991; van Driel, 1998; van Driel, Verloop, de Vos, 1998).

Carter (1990) defined PCK as "what teachers know about their subject matter and how they translate that knowledge into classroom curricular events" (p. 306). She also suggested that PCK was the "learning-to-teach" problem of "translating knowledge from one form to another, from propositional to procedural, than unraveling the meaning of complex experiences" (p. 306). Magnusson, Borko, and Krajcik (1994) described PCK as "an important construct for describing the role of teacher knowledge in facilitating student knowledge development, particularly for a complex subject matter such as science" (p. 4-5). Some researchers (e.g., Magnusson, 1996; Magnusson, Borko, Krajcik, & Layman, 1992; Magnusson, Borko, & Krajcik, 1994; Magnusson, Krajcik, & Borko, in press) have spent considerable time researching PCK in science education. Some studies have focused on teachersí knowledge structures and representations and how these have influenced instruction (Gess-Newsome & Lederman, 1995; Lederman & Latz, 1993). From these studies PCK was linked to the application of teachersí knowledge structures to pedagogy and to teacher certification. Despite the studies done by Magnusson et al., few other studies in science education have focused on the use, development, representation, and conceptualization of PCK.

Teacher Beliefs

Pajares (1992) stated that teacher beliefs should be a focus of educational research because the results and conclusions can inform educational practice. The use of beliefs as a theoretical framework for investigating why and how teachers initiate educational reform has been studied (Battista, 1994; Pajares, 1992; Tobin, Tippins, & Gallard, 1994). Science educators have also used teacher beliefs as a tool to understand why teachers act, react, and implement science education reform efforts (Beck & Lumpe, 1996). Pajares (1992) stated, "They [beliefs] travel in disguise and often under alias -- attitudes, values, judgments, axioms, opinions, ideology, perceptions, conceptions, conceptual systems, preconceptions, dispositions, implicit theories, explicit theories, personal theories, internal mental processes, action strategies, rules of practice, practice principles, perspectivesÖ" (p. 309). Beliefs are assumed to be the best indicators of why individuals make certain decisions (Bandura, 1986; Beck & Lumpe, 1996; Haney, Czerniak, & Lumpe, 1996; Nisbett & Ross, 1980). For teachers, beliefs effect how a teacher perceives and judges behavior. Ultimately, these perceptions and judgements influence how a teacher performs in the

classroom. Understanding the belief structures of in-service and prospective teachers was fundamental to improving their professional development and teaching practices (Pajares, 1992). Beliefs act as referents for actions, and can be interpreted as what and why a teacher accomplished a goal (Tobin, Tippins, & Gallard, 1994).

In recent years there has been a renewed interest in investigating teacher beliefs and their effects on teaching (Bryan & Abell, 1999; Cornett, Yeotis, & Terwilliger, 1990; Hashweh, 1996; Lantz & Kass, 1987; Richardson, 1996). For example, Hashweh (1996) determined that teachers holding constructivist beliefs (a) were more likely to detect student alternative conceptions; (b) have a richer repertoire of teaching strategies; (c) use potentially more effective teaching strategies for inducing conceptual change; (d) report more frequent use of effective teaching strategies; and (e) highly evaluate these teaching strategies compared with teachers holding empiricist beliefs. Even though researchers have determined that beliefs inform classroom practice, Lederman (1992) pointed out that the presumed relationships between teacher beliefs and classroom practices were too simplistic relative to the realities of the classroom situations. What was needed was an additional concept, such as PCK, in which researchers could view the relationships in more detail. For example, Brickhouse (1989, 1990) found that the classroom actions of two experienced teachers reflected their beliefs of what science is and how students learn science. However, a beginning teacher in the study used unpredictable actions that were not aligned with his beliefs.

Beliefs have been used as a central framework for investigations in science education (Bryan & Abell, 1999; Haney, Czerniak, & Lumpe, 1996; Hashweh, 1996; Luft, 1999; Oliver & Koballa, 1992; Tobin, Tippins, & Gallard, 1994). Tobin, Tippins, and Gallard (1994) defined belief "as a form of knowledge that is personally viable in the sense that it enables a person to meet his or her goalsÖThis can be undertaken only in a social milieu" (p. 55). There are factors which enable and constrain how a person implements his/her beliefs. A teacherís personal science background, peers, teachers, and personal traits facilitate a teachers transition of beliefs into practice (Palmeri, 1995; Tobin, Briscoe, & Holman, 1990). Context, socio-cultural, and institutional factors constrain the implementation of beliefs into classroom practice (Palmeri, 1995; Roth & Roychoudhury, 1993 & 1994; Tobin, Briscoe, & Holman, 1990).

Rationale for the Study

Nisbett and Ross (1980) stated that belief was a type of knowledge. However,

Rokeach (1968) stated that knowledge was a component of belief. Kaggan (1990) stated that teacher beliefs were viewed from a special kind of personal knowledge: a teacherís tacit knowledge. This knowledge is gained, often unconsciously, through the role they play with classrooms, students, the nature of learning, curricula, and goals of education. These contrasting representations of a definition of beliefs provide a context in which to use beliefs as a theoretical framework for studying the development of a knowledge base ñ pedagogical content knowledge. Cornett, Yeotis, & Terwilliger (1990) stated that there was a lack of research related to science teachersí beliefs and their impact on curricular and instructional practice. In addition, there is no consensus on the relationship between a knowledge base and beliefs. The following research questions guided this study.

1. How does PCK develop in prospective chemistry and physics teachers?
2. What model might be constructed to show the relationship between teachersí beliefs in teaching and PCK?

Methodology

The inquiry process that guided this study was qualitative in nature; one that was a case study in both theory and action (Merriam, 1985; Stake, 1995, 1996; Yin, 1993). The case study was conducted with 2 prospective secondary chemistry and 2 prospective secondary physics teachers in two settings: a secondary science curriculum class, and a subsequent student teaching field experience. These cases represented the unit of analysis for the study. The focus of the inquiry was on the cognitive development of PCK as influenced by personal beliefs. The questions the researcher brought to the forefront in this study (both implicit and explicit) were informed by his experiences in teaching chemistry and physics in a secondary context and by knowledge of previous research on science teachersí learning and teaching.

Context of the Study

This study took place in a secondary science curriculum class taught at a large university in the Southeast and in secondary science classrooms serving as student teaching placement sites. The curriculum class met five days a week for one hour. The goals of this class for the students were to "explore and experience the role of a science teacher in curriculum development and implementation as: 1) a liaison for the discipline of science and its nature and history, 2) a science communicator, 3) a multicultural educator, 4) an ethical decision maker, and 5) a school-based reflective practitioner." The researcher

acted as a participant observer during the secondary curriculum class and the studentsí field experiences.

Participants and School Settings

Four females volunteered to be part of this study. These were the only four prospective teachers with a background and interest in chemistry and physics. Randi was a white female in her mid-twenties who received a Bachelors of Arts in chemistry from a small liberal arts womenís college in the Northeast. Due to the small size of her college, Randi had the opportunity to experience instrumentation and more personal contact with the professors not available in larger universities. Randi was placed in Eastside High School in the suburbs of a large rural town. The school had approximately 1200 students, grades 9-12. The ethnic make-up of the school was 55% black, and 42% white. Randi followed the curriculum that was laid out in the high school text she was using, Addison-Wesley, Chemistry 4th Edition. She supplemented the textbook with labs and activities from other resources in the classroom bookshelf.

Amy was a white female in her early twenties who received a Bachelors of Science degree in chemistry from a medium size rural college in the Southeast. While in college, Amy tutored mathematics and chemistry. She worked for a year in a veterinary clinic after she graduated. Amy was placed in Green Hills Middle School in a rural county. The school had approximately 670 students, grades 6-8. The ethnic make-up of the school was 60% white and 39% black. Forty percent of the students were on free lunch. Amy used the Alabama Integrated Science Curriculum in her seventh grade class. This curriculum included taped telecasts, worksheets, hands-on experiments and activities, science pamphlets for each unit and additional printed and electronic information. She did not always follow the curriculum as specified; she added some examples and demonstrations, as well as deleted some items of the curriculum. Due to studentsí low reading scores on national standardized tests, twenty minutes a day were set aside in all classrooms for students to "free read." The school did not meet the state minimum performance in the area of science.

Maggie was a white female in her mid-twenties who received her Bachelors of Arts degree in physics from a small womenís college in a large metropolitan city in the Southeast. While in college, Maggie worked in an observatory on campus giving demonstrations and explaining the "heavens." After undergraduate school, Maggie attended graduate school in astrophysics at a large Midwestern school for one year. As a graduate student, she was given the

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opportunity to tutor, teach lab classes, and serve as a substitute lecturer for some classes. Maggie was placed in Jackson City High School in a small rural town. The school had approximately 600 students, grades 7-12. The ethnic make-up of the school was 81% white and 18% black. The schoolís graduation exams in science were above the state average. Maggie taught physics for nine weeks, eighth grade Earth science for five weeks, and chemistry for two weeks. Maggie based her curriculum and instruction on Modern Physics, Holt Rhinehardt Winston, 1984.

Tami was a white female in her mid thirties. She graduated with a Bachelors of Science degree in pharmacy. She spent the past 11 years working as a pharmacist. During this time she continued to educate herself in science by taking courses in physiology and pharmacology. Tami was placed in Longview High School in a semi-rural area, located on the periphery of a large city. The school had approximately 850 students, grades 9-12. The ethnic make-up of the school included 81% white, 10% Hispanic, and 7% black. Due to the large population of migrant families and second language students, the principal mandated that each class include weekly vocabulary tests as part of the curriculum. Longview High School scored blow the state average in science on the Test of Achievement and Proficiency. Tami taught one class of Physics with eight students in it, and four classes of Physical Science. She based her physics curriculum on Prentice Hall Physics by Merill.

Data Sources

Multiple data sources were used during the research process. Structured and semi-structured interviews were conducted with the prospective and classroom teachers. Documents pertaining to the secondary science methods course were collected (e.g., philosophy statements, handouts and course syllabus) and used in generating questions asked during interviews. Field notes were taken during the methods class and the student teaching field experience. Participants were asked to keep reflective journals about their experiences and thoughts during the methods class and the practicum and student teaching field experiences. Participants were also asked to share and discuss classroom projects and assignments.

A variation of the microgenetic method was used to study the development of PCK. The microgenetic method is a procedure whereby the participants received frequent encounters with the same task over a period of time (Siegler and Crowley, 1991). Participants were able to respond to a task (vignettes) over the course of two stages of teacher certification lasting one year; science

methods class and student teaching field experience. The vignettes created for this study contained potentially problematic incidents that could easily happen in any science teacherís classroom (Stivers, 1991). The administration and use of the vignettes as a heuristic tool in this study were purposeful. The vignettes constituted a modified intervention strategy designed to facilitate inquiry.

Vignettes

There were many vignettes found in the literature that focused on pedagogical issues while neglecting content (Greenwood & Parkway, 1989; Kowalski, Weaver, & Henson, 1990; Shulman & Colbert, 1988; Silverman, Welty, & Lyon, 1992; and Walen & Williams, 1995). The vignettes developed for this study contain pedagogical issues (e.g., classroom management, student learning, teaching styles and methods, and multicultural issues), inaccuracies in science content, and questionable methods for teaching the content. Several researchers suggested processes for creating vignettes (Lieberman, 1987; Miles, 1987; Stivers, 1991; and Walen & Williams, 1995). The vignettes used for this study contained the following components; an introduction of the setting, a description of the participants, an explanation of the problem, a description of the interacting dimensions found in the classroom, the dialogue between participants, and a possible major event worthy of attention by the teacher.

The researcher administered the first and second vignettes to each prospective teacher four times, every three weeks, during the secondary science curriculum class and the student teaching field experience. Depending upon how each participant responded to the vignette, the researcher asked either probing questions related to her initial responses, or asked a set of pre-determined questions. The questions were open-ended in the style of Spradleyís (1979) "grand tour" questions, and did not lead the student to explicate correct answers.

Content topics taught during the vignettes served as a context for each vignette. The misrepresented content and pedagogical items were used as stimuli for conversations and questions about how the participants would teach solutions, thermodynamics, and linear motion in a similar situation. The participants were asked specific questions pertaining to content accuracy, the methods of instruction, and contextual situations.

Overview of the Chemistry Vignettes

The first vignette entitled *Solutions* (VA) described a teacher who used the

jigsaw method of cooperative learning to teach a chapter on solutions over seven days. The students in the vignette were given individual and group grades for their work. The teacher demonstrated some content concepts of the chapter, but left the responsibility for other demonstrations and explanations of concepts to the students. The situations embedded within this vignette focused on 1) how solutions were taught by studentsí peers, 2) how solutions were made, and 3) how an angry parent objected to the group grading system for the solution unit.

The second vignette was entitled *Heating the Discussion with Thermodynamics* (VB). In this vignette, the teacher used a variety of pedagogical methods to teach the concept of heat, temperature, and other concepts related to thermodynamics. He demonstrated concepts, lectured, lead a discussion, and had the students complete a mini-lab. The situations embedded within this vignette focused on: 1) a hair dryer as an incorrect model for electrical energy, work, and heat, 2) the use of a blender and thermometer to detect temperature changes as part of a demonstration, and 3) the teacherís lack of concern about a student dropping out of class because the studentís learning style did not match her instructional methods. Below is an excerpt from the vignette:

> Ö"OK, letís get on with the task ahead of us. Take out your notes. Iíll be lecturing some today, and youíll have homework every night on what we have learned. Thermodynamics deals with the microscopic level of chemistry, such as the kinetic energy of atoms and molecules, pressure, temperature, and their roles in chemical reactions. We have a basis for thermodynamics in the conservation of energy. Just like the conservation of mass in a chemical reaction, there is conservation of energy. Energy or matter is neither gained nor destroyed in the process of a chemical reaction. In the microsystem, energy is conserved, but not in the sense that we know it. Heat can be transferred from molecule to molecule. In reactions, heat energy can be used up or created. Heat itself cannot be measured directly. Instead, heat flow must be calculated from its effect on the temperature of a given quantity of a substance. Therefore, heat is always measured indirectly."
>
> "Here is a good analogy or model between the relationship of heat and work and energy: Consider a hair dryer with an electric fan and a heater. The electric fan does work on the air by forcing the air to move. The heater converts electrical energy to heat, which increases the temperature of the air. The heated air does work on the water molecules in your hair. The kinetic energy of the water molecules is increased so that they

evaporate."

Peter had gotten up during this brief introduction and walked over to the pencil sharpener to sharpen his pencil, "Damn, this thing still doesnít work well." He sat down while Mr. Jackson continued.

"Absolute zero represents the coldest temperatures we know. It is the temperature at which no atoms move. When you raise the temperature, you also raise the heat, and the energy, and the motion, and the work. All of these principles are directly related to each other. As an object becomes hotter, its atoms and molecules move faster. As an object becomes colder, its atoms and molecules move slower."Ö

The thermodynamic vignettes (chemistry and physics) for the second response phase of the study were developed by the researcher to determine if the prospective chemistry teachers viewed thermodynamics from a different paradigm than the prospective physics teachers. In developing the vignettes the researcher made the assumption that thermodynamics was more typically represented from a microscopic perspective in chemistry and a macroscopic perspective in physics. The researcher based this assumption on his analysis of how thermodynamics was represented in common chemistry and physics secondary textbooks Magnusson & Krajcik, 1993). Questions asked during the course of the vignette interviews did not directly address this perceived difference.

Overview of the Physics Vignettes

The first physics vignette was entitled *Linear Motion* (VC). In this vignette, the teacher used a variety of teaching methods, both traditional and non-traditional, to introduce the concepts of speed, velocity, and acceleration. The teacher and students discussed, calculated, and defined linear motion concepts using a remote controlled car in the middle of the classroom. The situations embedded within this vignette focused on: 1) the incorrect teaching of some concepts of linear motion, and 2) a student who dropped the class because his learning style did not fit well with the teacherís instructional methods. Below is an example of the vignette:

ÖThe bell rang as Hakeem sat down in a seat near the front of the class. Mrs. Johnson strolled into the classroom with a remote controlled car. As she walked in she began to talk, "Go speed racer, go speed racer, go. What am I doing?"

No immediate reply came until she ran over a studentís foot with the four wheel drive car. "Youíre acting weird," said one child.

"Youíre playing with your sonís Christmas gift," yelled another student.

At that moment Hakeemís friend, Jesus strolled into class late. Mrs. Johnson seized the opportunity by asking Jesus very casually, "Jesus, why do you think Iím playing with this remote controlled car?"

Hakeem was surprised that Mrs. Johnson didnít scold Jesus for coming in late. Jesus replied, "Youíre showing that something moves."

Mrs. Johnson continued her asking, "Go ahead and put your books down right there and help me with this demonstration. What Jesus and I will do for you today class is demonstrate the fact that linear motion can occur on the ground or in the air, and that motion has two main components, velocity and acceleration. Jesus, why donít you take control of the remote for a while."

Mrs. Johnson walked over to the board and began to draw a straight line across it. While she was doing this, students were getting out their books and papers to start writing down all that she was about to do. Some students were sitting on desks, others were on tables, and some were actually in their seats. She marked the beginning and end of the line with hash marks. The beginning had a zero and the end had a question mark.

Jesus was rolling the car over peopleís feet and bumping it into desks and tables. Hakeem thought for sure that Jesus would get into some serious trouble for being late and for distracting the students with the car. Mrs. Johnson ignored Jesus and continued with the diagram. Below the line she put the letters "v" and "a".

Mrs. Johnson turned back around to see Jesus bang the car into Marieís foot. "Jesus," stated Mrs. Johnson with a cool demeanor, " could you show us and explain with the car what velocity is or does."

Jesus thought for a moment, and brought the car back to where he was. He looked at the long stretch of floor and started the car forward. The car raced to the back of the class when Jesus began his explanation, "The car has a velocity of 5 miles per hour."

"How do you know that it has that particular velocity?"

"Because it seems like it does, because it certainly isnít 100 mph. I should know I have driven that fast before." The class erupted with laughsÖ

The second physics vignette was entitled *Heating the Discussion with Thermodynamics* (VD). This vignette was very similar to the chemistry vignette on thermodynamics. Similar misrepresentations of heat and temperature were presented. The physics vignette contained a different explanation about kinetic energy and temperature being due to a macroscopic perspective, whereas in the chemistry vignette, the explanation of kinetic energy was based upon movement of individual molecules.

Data Analysis

All text data (interview transcripts, documents, field notes, vignette responses, and journal entries) were analyzed by qualitative content analysis (QCA). Emic categories were established based upon the units of meaning and their relationship to the research questions, and clusters of categories helped to diagram a scheme which represented findings relevant to the research questions (Strauss, 1987). The data were re-read and categorized into broad categories. Sub-categories were determined to organize the data further. Some of the emergent broad categories served as the foundation for questions in the participantsí reflective and exit interviews. .

Results

Beliefs

Teaching Style

Randiís beliefs about teaching science came from her experience as a laboratory instructor during her undergraduate senior year in college in which she taught a nursing chemistry laboratory. Reflecting on her experience as a laboratory instructor, she recalled that "it was a little intimidating at first and I think I went in kind of like, well, how am I to teach them. And I had to reinvent how I taught things" (Initial interview, 10/7). One of Randiís main beliefs about teaching, which stemmed from her experience as a laboratory instructor, centered on the need for flexibility. "I think I learned you have to be flexible more than anything. Everybody learns differently, so you have to do the best

you can" (Initial interview, 10/7).

At the end of her science curriculum and methods classes, Randi was more aware of the complexities of teaching, especially how they related to students:

> I would say that you have to use diversity to incorporate different styles within your teaching. I know you have to be aware of different backgrounds of students, where they're coming from, whether they...be it cultural differences, or the simple levels of your classroom. You could have a student in chemistry that's only taken pre-algebra, but somebody else has taken algebra. So you have to adjust it and make things easier on a level playing ground (Reflective interview, 12/12).

Randiís perception of teaching was that every student learned differently, and those differences made it essential for a teacher to use a plethora of methods. She also believed that there was a definite difference between teaching science and teaching other subjects.

> I think with science, a lot of it, at least for me, is hands-on. Like to relate things into everyday. History, it's over and done with while you can recreate it, you're not formulating that many new ideas about it. But with science, it's always changing. And you can change with each thing you do or the students can have new perspectives on something. (Initial interview, 10/7)

For Randi, science was a dynamic discipline that was not stagnant or fixed. Randi believed that students couldnít relate to history well, "but with science, I donít want to say itís more practical, but itís kind of like building blocks; you can make things from it, and itís hard to make things out of history" (Reflective interview, 12/12).

Initially, Amy believed that teaching science involved traditional methods such as lecturing, completing worksheets, reading, and conducting laboratories. Not surprisingly, her beliefs were based upon how she learned science while in high school and college. While in high school, Amy had to "self-motivate all the way through, which wasnít a bad thing," because her teachers were dry and boring (Initial interview, 10/5). She stated that science during these formative experiences was taught in the traditional lecture format. Amy believed demonstrations would work best if they were applicable to the studentsí home and communities.

For Amy, science was a body of facts that was more practical in nature than history.

> The body of facts, it's there and there are things you have to put down in learning and memorize, but, I had rather that they know, I guess the more practical, or something that they could see in their kitchens or in their driveway (Initial interview, 10/12).

Amy described history, on the other hand, as "pretty much just history; it happened on December 17, 1862" (Reflective interview, 12/11). She distinguished between the two subjects primarily on the basis of their content matter, practicality, and the extent to which major concepts associated with subject were "concrete." While she felt that science "facts" had to be learned, she believed they could be taught in ways that sparked studentsí interest by showing the practicality of science. Amy believed that science could be discussed, explored, and discovered.

Maggie believed that the best teaching style was one that involved the teacher in making content applicable to the lives of the students. "I want to be able to make it accessible to the real world" (Initial interview, 10/12). Maggie developed her opinion about an appropriate teaching style from her experience as a laboratory instructor in graduate school. The laboratories in graduate school were generally regimented and non-flexible in terms of content and procedures. Maggie realized that students were not learning the material well enough to understand the concepts, because the course professor taught the content as facts for the students to memorize. As a laboratory instructor, Maggie tried to relate the material to the studentsí lives as much as possible. Another aspect of Maggieís teaching style was reflected in her beliefs about how students learn. Maggie felt that the particular methods she would use as a teacher would be driven by the learning styles of students. She stated that "you have to look at the content and students before choosing a method" (Initial interview, 10/12). As a teacher, Maggie wanted to "reach different students because they learn differently" (Initial interview, 10/12). Maggie believed that the best teaching style focused on the students.

At the end of her student teaching field experience, Maggie still believed that she had not changed her view of science teaching.

> I donít think so. I donít think itís different. Iíve seen some more options in terms of methodologies than I had before. Iím used to a lot of straightforward and cookbook laboratories from my own education. But

> aside from that, I donít think the viewpointís incredibly different. Maybe this is a better way to put it. I havenít seen anything in the last two years thatís just dramatically changed my viewpoint. (Exit interview, 4/11)

Even though Maggie didnít believe her philosophy of science teaching had changed, in actuality, Maggie did alter her view of science teaching. She was able to expand her knowledge about various teaching methods, and incorporate "extra items" into her teaching philosophy.

Tami based her teaching philosophy on how she learned science. "Well, recently I would have said lecture. Because that was when I was reflecting in 441 [Foundations on Science Education] I realized that when I pictured myself as teaching I pictured myself as lecturing" (Initial interview, 10/12). In her initial interview, Tami used an analogy to expand on her image of teacher as lecturer.

> I guess it's what I've always had. And when I pictured myself as a teacher, I picture myself in front of the class lecturing...Like I wrote my rationale paper I see myself more as a conductor. You kind of orchestrate the students as they learn and I realize different students are on different waves. Some work better with really concrete objects, hands on, and some work better in abstract. It just depends on the kid, and you kind of coordinate their learning. But originally I see myself as a lecturer, which I thought was good. (Initial interview, 10/12)

After taking some preliminary education classes, Tami began to change her vision of science teaching. During her science curriculum class, Tami began to realize that teaching was "an active process." "I realize people do better when they're actively involved in learning rather than passively reading or sitting there listening...I like to see as well as hear it" (Initial interview, 10/12). Tamiís belief in active learning was supported by her essay: "Why I should be a teacher of..." (Science curriculum syllabus).

> I am learning about constructivism, problem solving skills, inquiry teaching. It is really exciting, but itís also a little scary. I realize how different it is than when I was in school. It also shows me how much I have to learn and prepare. (Essay assignment #1)

During the science curriculum class, Tami began to realize that some methods of teaching science were different than how she learned science.

Tamiís original vision of science teaching incorporated the belief that science

should be relevant to studentsí lives. "You've got to make it relevant to the kids who don't think it's going to be relevant to them" (Initial interview, 10/12). "I guess this is my goal; to show them science really is relevant and how they can use it, no matter if they choose janitorial work or are a supreme court judge" (Essay assignment #1). Tami maintained this belief throughout her teacher preparation program and into her student teaching (Field notes, 4/11-5/19).

Personal Learning Style

Because Randi believed that students learned differently, she felt that as a teacher she would use different teaching methods and styles. The basis for this belief was a reflection of how she, herself, learned best, "Hands-on. If you asked me to read a book I couldnít tell you what I read" (Initial interview, 10/7). Not only was learning by the book difficult and hands-on instruction beneficial for Randi; she expressed a need to have the content situated in a practical application or have it relevant to her life.

> I cannot take something that I read, process it and regurgitate it to you. If you show me this mechanism physically, or put it to some way that I can incorporate it into something that Iím going to use, then yes, I can do it. Like calculus. It took me three tries to get through calculus. Because for me itís just a formula on the board itís too abstract. If you applied it to chemistry equations, Iíd get it like this. I had no problems in my chemistry class because of calculus. But to sit and to say, OK, I memorized twelve different equations and then to be able to pick that one out to go to this one specific problem, I couldnít do it. (Initial interview, 10/7)

Because Randi learned best from hands-on and practical examples, she realized that her teaching would reflect what she perceived to be a beneficial way to learn.

Initially, Amy believed that most students would learn in the same ways that she learned science. She described her own learning style as one of listening and not doing science. Amy stated that she didnít "have a whole lot of experience learning by doing because that's not how many of my classes have been taught, my science classes anyway" (Initial interview, 10/5). She found it difficult at first to sit in education classes and participate in discussion activities (Field notes, 1/24). From her experience, Amy felt that if students came to class and listened to the lectures, they would easily be able to learn science. Amyís ideas about learning science changed as she progressed through the science teacher preparation program. She came to realize that students learn differently,

and consequently, a repertoire of diverse teaching methods needed to be developed (Field notes, 2/16). Although learning science, for Amy, initially consisted of reading the book, listening to lecture, and not doing science, she eventually expanded her conception of science teaching to include group interaction and discussion, videos, laboratories, and problem solving activities.

Maggieís philosophy about teaching was partially based upon how she learned best. Maggie, herself, learned best through involvement in the process of teaching others. "It's one of the ways I learn best and I know something if I can teach it to others" (Initial interview, 10/12). Maggie believed that her personal learning style would affect how she taught science. As a student, she learned the content a specific way; as a teacher, she realized that not all of her students would learn from the lecture and problem solving style she had experienced. "As far as the learning process itself, I guess because I have so much math and physics background that working problems helps a lot for me" (Initial interview, 10/12).

Tami felt that she learned science best in a traditional way; through lecture, reading, and working problems from the book.

> Writing...Like if I'm reading something a lot of times I'll take notes or if I'm getting study questions, I write out my answers. I learn best when I write...I classify things and do outlines...I'm more of a visual. I'm a visual person. (Initial interview, 10/12)

Because Tami felt she was a visual learner, she saw herself as a lecturer writing facts, equations, and problems on the chalkboard. During Tamiís teacher preparation program, she realized that students learned differently, and that her conceptions about teaching science were changing. "I want my students to learn to question; I want them to look beyond the superficial; I want them to ask why, and have the evidence be substantiated" (Essay assignment #3). Before the science curriculum class, Tami felt that her learning style translated into a lecture method. After her student teaching field experience, Tami came to realize that she actually learned best by doing, and this translated into how she eventually conceptualized teaching physics and physical science.

Conceptualizing an Effective Teacher

Randi believed that an effective teacher knew her students, knew her subject matter, and recognized that kids were different. Her beliefs about effective teaching influenced how she viewed the teacherís role during instruction.

Teaching the nursing laboratory helped Randi realize that knowing the content was important; not only for answering questions, but for introducing laboratories and making chemistry relate to studentsí lives (Initial interview, 10/7). As Randi saw it, the teacherís role was to help the students in class and in life, and to make chemistry approachable (Journal, 10/13). In order to become an effective teacher, Randi believed that she would have to learn through "trial and error" and "being in the middle of it" (Initial interview, 10/7).

Amyís image of an effective teacher focused around the nature of student/teacher relationships. She believed that an effective teacher talked *with* students instead of talking *to* students, a belief which was fostered through positive personal experience with her high school science teacher. Amy also believed that students should feel comfortable around their teacher so that they could freely approach with questions or concerns. Mutual respect between the students and the teacher was an attribute of effective teaching which Amy highly valued; accordingly, Amy believed that an effective teacher had to interact well with her students. Amy also discussed attributes of effective teaching in terms of how content was taught. An effective teacher was "excited about it [the content], or even if they werenít excited it wasnít monotone, and they moved around a lot, they just didnít sit at the desk" (Initial interview, 10/5). Amy also believed that a teacher had to know the content well enough to be able to lead discussions.

At the beginning of the study, Maggie believed that an effective science teacher cared for students, respected her students, and understood the content. "If you go in and you spout out all this information and don't care whether they get it or not, then that's going to come through" (Initial interview, 10/12). "So I think you have to show a respect for your students" (Initial interview, 10/12). "I think it's important to be knowledgeable about your subjects" (Initial interview, 10/12). At the end of the study, Maggie still believed that an effective teacher had these qualities. "But if I can make it simple so that other people who arenít science majors can understand, then thatís something that I should share" (Exit interview, 4/11).

After having spent a few weeks in the classroom setting during her practicum experience and student teaching field experience, Maggie described four attributes that she believed were at the heart of effective teaching.

> *Patience* . This is something that can be improved upon, but some people never have it. A teacher has to be patient with many things, including lack of understanding, discipline, dealing with parents, dealing with

administration, and more.

Willingness to work beyond the classroom . Any student who is willing to work and learn outside of the classroom deserves a teacher to help and guide them. Not all learning is from a textbook, it is not always done from 8 to 3. This just takes a commitment to the students. Let them know youíre there for them at any time, whether for academic or personal reasons. And get involved, both at school and in the community. The students will see that.

Flexibility . Being inflexible will gain you nothing. Flexibility shows others (the students in particular) that you understand about extenuating circumstances, and that youíre willing to change if a better option is offered. Setting more guidelines and fewer hard-and-fast rules allows for flexibility.

Enthusiasm . If youíre not excited about your subject and about teaching, then how do you expect your students to be excited about learning? Off-days happen, and thatís OK, but overall a good teacher will be excited about teaching and learning. (Journal entry, 1/21)

These attributes were based upon how her cooperating teachers modeled science teaching. Maggie wanted to incorporate these attributes into her own teaching style.

Tami initially believed that an effective teacher had to be creative, know their subject matter, know their students, and use different teaching methods. These attributes effected how Tami perceived teaching.

> Teachers must know their subjects. They must know their students. They must be willing to always work on their lesson plans to make them as creative as possible. And to find new ways to reach the students that don't get it. Because there's always going to be somebody that doesn't...different angles work better for different students. You've just got to find the angle that works. (Initial interview, 10/12)

Tamiís perception of a strong and effective teacher changed little during her teacher preparation program, except to include an affective concern for the treatment of students as individuals. "An excellent teacher cares for her students...is creative...is fair...has a strong knowledge base...strives to create a classroom environment where learning can take place" (Essay assignment # 4).

"Part of being a good teacher are just characteristics; respecting the students, understanding students, sympathizing, empathizing, and how much you like the students" (Reflective interview, 12/9). Tamiís changing philosophy of an effective teacher influenced how she taught during her student teaching field experience.

Emergent Broad Categories

Chemistry

Chemistry concepts were deemed magical. Amy found instances in both vignettes in which she could describe the topic or demonstration as too magical to comprehend. In Vignette A on solutions, Amy circled, on her copy of the vignette, a quote by Mr. Norton in which he stated "The solution had so much solute in it that it just turned to solid." Amy noted that no explanation was given to the students about the process in which a super saturated solution of sodium acetate solidified.

> All right, he's making them the saturated solutions and it says that the solid particles were just buzzing around there at fast speeds until the solute molecules are no longer solid, but in solution. And...all right, it kind of makes it sound like it's magic. And, I guess it maybe it just bothers me a little bit. Because it's not really magic...And then he does that again, because he says when he puts the beaker into the water, he says that, it has so much volume that it just turned to solid. And that kind of makes it sound like it's magic, too. Which I read another paper on what makes chemistry hard is the level of information. That's part of why students don't like chemistry is because it's not very real to them, things just kind of happen. (VA4)

To Amy, the process of a saturated solution turning into a solid was being conveyed as magical to the students, when in fact there was a scientific explanation for the occurrence. Amy believed that the super saturated solution demonstration could have been taught more effectively if Mr. Norton would have used alternative terms and explanations.

In her response to Vignette B, Amy discussed another content topic which she believed students might perceive as magical. In this vignette, Mr. Jackson made a comparison between the conservation of heat and the conservation of energy. The vignette described how Mr. Jackson explained the conservation of energy: "Heat can be transferred from molecule to molecule. In reactions, heat energy

can be used up or created" (VB). The term "created" also bothered Amy:

> Later on, it says that in a reaction heat energy can be used up or created. I don't really like created. It goes back to what we talked about before, about things being magically done. And he just creates this thing. And that might just be in my own head. Maybe other people don't think that, but. I feel that created is maybe not the best word he can use. I can't think of another one right off the top of my head to put there. Can be used up or given off. (VB1)

Amy could not think of another word to use in place of the term "created" except "used up" or "given off." To Amy, "created" meant that something appeared for no reason, out of nothing. This concept was troubling for Amy because she worried whether students would be confused and would later develop misconceptions. "It means you just created it out of nothing. It means that it wasnít there before and you created it, kind of like magic" (VB1). Amyís trepidation with the term "created" was based upon her feeling that chemistry was an abstract content that had concepts which were difficult for students to understand (Informal interview, 11/20).

Amy revisited the idea of "created" in her third response to Vignette B. In this response, Amy was able to determine that her concerns, related to how Mr. Jackson taught conservation of energy, were actually based upon his use of language.

> Down here he says, conservation and energy, energy is conserved, but then he says that in reaction, well, he's talking about the...I took it to mean heat energy could be, is conserved within your system. But then he says that energy can be used up for creating. And to use it up, then you're not really conserving it because "used up" to seems like it's gone...Because "used up" to me just sounds like it's gone and it's not there anymore, and that's really not the case. It's still there, it's just not in the same place it was to start with. (VB3)

Amy realized that Mr. Jacksonís use of the concept of energy was correct, but the manner and method in which it was explained was vague. She believed that a misconception about chemistry was being conveyed to students. Amyís remedy for teaching this concept was: "say that energy can go from one thing to another, and so what youíre looking at may have more or less energy, but that energyís not gone, itís just in another spot" (VB3).

Chemistry concepts were deemed abstract. Randi believed that chemistry was abstract because students couldnít "see" the atoms or molecules. Randi felt that if the students could "see" chemistry, they would develop a better understanding of chemistry concepts. Randi had a difficult time conceptualizing the demonstration that Mr. Jackson conducted (Vignette B) in which he warmed up a bowl of water with a blender. "Well this, and I need to try this at home, but I don't have a blender. Really if you put a blender in water that's not really...it's moving the molecules but I can't see that it's speeding up the molecules" (VB3). Randi believed that if she had a problem "seeing" the concept of the demonstration, then students would have an equally difficult time understanding abstract concepts.

Randi also focused on another content item in Vignette B which she believe illustrated the abstract nature of chemistry. "And itís [Law of Conservation of Energy] a very abstract idea, I mean yeah, you canít see energy being created because itís not, or destroyed" (VB3). She felt that the concept was difficult to understand. Part of Randiís confusion surrounding the meaning of conservation of energy was related to the language used by Mr. Jackson to explain the concept. Randi felt that the language used to teach the concept of conservation of energy should be specific and free of confusing words like "created." Randi believed that energy was a difficult topic for students to comprehend due its abstract or non-visual nature.

> I think itís a hard topic for anybody, because a lot of these things, unfortunately you canít see energy. Like you canít hold energy in your hand. And I think just that in itself, that itís not like you can actually see. That you can see this and you know that thereís energy working through there. Thereís energy making it run, but you canít see it. And thereís no way, and I guess sometimes when you have such abstract things, I think that kind of makes it difficult,...because itís not like you can say, well, hereís a piece of energy. (Focus group)

For Randi, being able to relate the concept of energy to students at their level was a major component of "learning to teach" thermodynamics.

> I think because youíre always looking for ways to show it in more of a concrete way. Youíre looking for demonstrations, or replications, or anything you can actually give them to see. Like whether itís, we talked about a mole of a gas, and actually how big is a mole of gas? Actually if you take a five gallon pail, the volume of that five gallon pail is a mole of air. And I knew, until they can actually see it, well, thatís a pretty big

> amount, but that mole of gas and then I had a mole of water in a beaker, and a mole of salt in a beaker, and show them how they were all different. They all were not the same thing. Just like a dozen doughnuts, and a dozen cars, and a dozen pencils, and theyíre all still a dozen. They all weigh differently, and so I try to, you try to give them concrete things or examples of concrete things that can relate to what youíre doing. (Focus group)

For Randi, "learning to teach" thermodynamics involved developing examples or demonstrations which helped students "visualize" what they couldnít see.

For Randi and Amy, not being able to "see" phenomena well, made chemistry more abstract than biology or physics.

> I think, a lot of chemistry is very abstract. Iím not going to...itís not easy. Itís not...I hate to say this, but itís not biology where you can see it. Itís not like, itís not concreteÖYou swallow something and you can see it actually going down. (Randi, Focus group).

Amyís cooperating teacher agreed that chemistry was a difficult subject to learn when compared with other science domains, due to its abstract nature. "The basic delivery system is the same - text, lecture, demos/laboratories. I feel that students may find biological concepts more applicable to their lives, or this could just be my bias" (Ms. Smith journal entry, 2/14/97).

At the end of Randi and Amyís student teaching field experience, they continued to think of chemistry as an abstract subject. However, Randi and Amy believed that chemistryís "non-concreteness" significantly effected their teaching only when an exception or corollary related to a specific topic was introduced or discussed with students.

> R: I would say that thereís not as many [corollaries] in the other two areas [biology and physics] as there are in chemistry. Like weíre studying covalent bonding and the kids learn how to put oxygen together and then to them, like and now weíre going to learn that oxygen is really an exception and then I hate you for it, thatís because, theyíre like, well, why do we learn all this and then thereís always an exception? Thereís always an exception. Doesnít matter what youíre studying, thereís an exception for just about everything.

W: And thatís part of the nature of chemistry?

R: Yeah.

A: Well yeah, and thatís also part of why I graduated not wanting to use my degree for I guess, industry. Because there I got into it, the more I really disliked chemistry because everything you learned was a lie. And that was just, everything I had been taught and we had to come and repeat every single day and write a billion times. And you didnít do it. The more you got into it, you find, well, thatís not ever true. But then you were taught to start with, that was just the gospel. (Focus group)

Chemistry was viewed from a microscopic perspective. Randi did not see any connections between the microscopic or macroscopic views of thermodynamics until she mentioned the microscopic view in a focus group interview. Randi did use the concept of molecular movement in some of her explanations of heat energy and temperature, but she never related those explanations to the microscopic view. "Well, they know that the molecules are already moving because we covered the kinetic theory. And that in order to change energy level you have to add in some kind of energy" (VB2). "He talks about the kinetic energy of the water molecules so we can say, so that they evaporate. Well, the kinetic energy increases, therefore, the temperature increases" (VB3). "Really if you put a blender in water that's not really...it's moving the molecules but I can't see that it's speeding up the molecules." (VB3). The discussion above suggests that Randi viewed energy and temperature from a molecular perspective.

Amy did not see any connection between the microscopic view of thermodynamics and chemistry. She did not mention the use of the term microscopic by the teacher in the vignette; however, she did discuss the molecular aspects of thermodynamics related to heat energy and temperature. "I mean I know that I've been told molecules are bouncing around all over the place...when they're heated, but then again that about the blender just doesn't really sound right to me" (VB2). Even though she used the term molecular, she did not have a good conceptual understanding of the relationship between molecules and thermodynamic principles.

As I was saying as the molecules move faster, the heat and temperature rise. This may again just be my conception which would make it sound like the molecules, but the heat and temperature are rising as a result of

> the molecules moving faster because you're adding the heat, to add the energy to make the molecules move faster, increasing the temperature. I think. So, what I'm trying to say was that this sounds kind of backwards to me, which may lead to misconceptions or not understanding. To change it, I would turn the sentence around, putting, as you increase the heat, the molecules vibrate, raising the temperature. (VB3)

Physics

Physics was a mathematically oriented discipline. Maggieís understanding of the relationship between math and physics was apparent in her initial interview. For Maggie, physics was a mathematical subject.

> I like...when I work problems I don't want to do ten of the exact same thing with just different numbers. I need to have it coming from a different viewpoint or finding a different, solve it with a different variable this time, or having to find something else first before you can get it and they need to change in complexity in order to feel like I've got it. Because otherwise I'll say, Yeah, I know how to do this type of problem, but I may not really know it. (Initial Interview, 10/12)

Maggie believed that teaching physics meant lecturing and working problems, and students could develop conceptual understanding simply by working the problems. She also believed that math was the best way to teach the relationship between the numerous variables used to represent physics concepts. "I guess because I have so much math and physics background that working problems helps a lot for me" (Initial Interview, 10/12).

Maggieís mathematical perspective influenced her responses to Vignette C. Even though the concepts in the vignette were introduced and taught in a conceptual manner and from a lower mathematical perspective, Maggie still relied on her knowledge of higher mathematics and physics from college to analyze whether the concepts were being taught correctly.

> The way I remember having it explained to me and when I've tried to explain it to other people is looking at it from a...from a fraction, from a mathematical basis. To start off and say, OK, the idea is that you take velocity and divide it by time. So what are the units, velocity, meters per second. Divide that by time which is second. And then if you manipulate the fractions to make it look so that it's not just a hideous looking thing on your paper, you can say, OK, that's...when you divide it, it's the same as

> multiplying by the reciprocal. It's easy to say. This thing is this. And with this, now you can see how that becomes meters per second squared. (VC4)

Even though Maggie believed velocity and acceleration could be taught using lower, non calculus, mathematics, she still planned to teach the relationship between velocity and acceleration from a mathematical perspective.

Maggieís belief that physics was math oriented influenced her teaching. At the beginning of her student teaching field experience, Maggieís lessons were lecture oriented. She introduced concepts by writing the equation on the board, followed by an explanation of the variables. Once the variables were defined, she worked through sample mathematical problems (Field notes, 1/24 and 2/14).

By the end of her student teaching field experience, Maggie had incorporated a wider variety of instructional methods into her teaching, but still relied on a mathematical approach to teaching physics concepts. For example, she introduced the concept of heat transfer to her students by explaining the purpose of a calorimeter. The following are field notes taken during her lesson on heat transfer.

> In another problem, she listed three items in the system. $Q_{lost} = Q_{gained}$. ëbecause we have three items, two are going to gain or lose heat. We know from the set-up of the calorimeter, that the temperature of the water and calorimeter will be the same. What will the temperature of the final system be if the temperature of the calorimeter and water are 21 and the silver bar is 100? We want to know what looses.í Then she proceeded to plug in the variables in the original equation. She answered a studentsí question, ëWe will ignore any heat loss to the atmosphere. It looks funky, but all I did was substitute $mc\Delta T$. We know all of these variables, and we need to find the final temperature. The equation is just algebra to find the final temperature. We want the delta T quantity to be positive so for heat lost it is subtracted, and in the heat gained, final temperature is first with the subtraction of the initial temperature.í (Field notes, 3/5)

Tami oscillated between her beliefs about teaching physics conceptually or mathematically. This oscillation was due to her strong math background and her cooperating teacherís masters degree in mathematics, and complicated by twelve years without using or applying her math skills. One reason Tami decided to specialize in physics during her teacher preparation program was

because she loved the subject matter and had always done well in math. "Probably because the math content. I love math" (Initial interview, 10/2). The relationship between math, physics, and physics teaching was made apparent by Tamiís cooperating teacher during her student teaching field experience. "She is very strong in math, and teaches primarily through formulas and problems. I told her I was primarily trained to teach concepts. We are hoping to learn from each other" (Student teaching journal, 3/31). Through Ms. White, Tami developed a better understanding of the mathematical nature of physics. Ms. White mentored Tami from the mathematical perspective, while Tami showed Ms. White how to teach from a conceptual perspective.

Although Tami wanted to teach from a conceptual perspective, the mathematical influence from Ms. White often impacted Tamiís teaching. At the beginning of her student teaching field experience, Tami was uncomfortable teaching from a mathematical perspective (Field notes, 4/23). "I think as she gets more comfortable. I think weíre going to begin to see in the next two to three weeks. Sheíll roll along in math" (Ms. White interview, 4/23). In Tamiís third response to Vignette D, Tami mentioned that her education classes never explained how to teach mathematical concepts in science.

> I'm still learning, especially with the math, it takes them longer to do it. Just for them to catch on, than I'm used to. And I don't know, just because I don't, we didn't have anything on like on methods, on how to teach math. So I don't know how something should take. And I didn't realize how much trouble just working those formulas, they're going to have. They forget to hit equals and all their answers are wrong. Or they go, well, I'm gonna, multiply and then I'm gonna subtract. They just can't do the simple algebraic formula. (VB3)

Tamiís perception of physics had changed from a mathematical perspective in college to a conceptual understanding during her teacher preparation, and finally to a combined understanding at the end of her student teaching field experience. "I don't remember that much about college physics, except it was so long ago I remember all the testing math problems" (Exit interview, 5/20). "Itís [physics] got a lot of math in there, a lot of math. Physics is math" (Informal interview, 5/10). By the end of her student teaching field experience, she had developed a more integrated view of physics and math.

> Math's a part of it. And you've got math as a part of it. But that is not the all of it. It's like half and half. It's part math, part concepts. And that was Ms. Fogleís problem with the conceptual physics book. It didn't have

> enough math for her. I think you can teach it, they're hand in hand. It's not all concepts and it's not all math. You can't make it, you've got to have both. (Exit interview, 5/20)

Even though Tami tried to teach physics conceptually, she learned that physics was intricately related to mathematics. Tami believed that her teaching style would ultimately reflect the integration of math with the conceptual component of physics. Both Maggie and Tamiís beliefs about teaching physics mathematically were influenced by their content background, cooperating teachers, and classroom experiences with students.

Physics was perceived as the most difficult subject. Maggieís concerns about physics being a difficult subject to learn focused on her belief that physics was an apparent dichotomy. Maggie felt that the dichotomy was that students feared physics even though it was extremely relevant to their lives. Maggieís practicum experience helped her realize that high school students were fearful of physics; not because of the math necessarily, but because of the concepts.

> But physics has a stigma about it. It's a dichotomy. It's completely realistic. And everyday life, it is everywhere you look. And you can find tons of real life examples, but nobody understands them. And so when you go into a physics class and you're thinking this is the hardest thing in the world, that it's harder than biology, the stigma is that it's harder than biology and that, it and chemistry are pretty close but it's probably harder than chemistry. And people have a fear of it. And I think by demonstrating it and by giving them examples more so than just getting up and saying, This is the equation for speed, this is equation for velocity, this is the equation for acceleration. People get turned off by them very easily and then I think the idea of doing lots of demonstrations and activities is good. (VC3)

> Physics to me is a dichotomy. In some ways it is intuitive. It occurs in everyday life and you canít get past it . To most people it is counter intuitive. For most people to get through it, they have to not believe it is difficult, fear factor, fear in general, but also physics. (Practicum interview, 11/20)

Maggie was surprised that most of her students were fearful of physics. She had anticipated that students taking physics in high school would not have any fear, because usually the brightest students took it.

Maggieís belief that physics was a difficult subject to learn was reinforced during her student teaching field experience. Her physics class had an enrollment of eight students. Maggie was surprised that only a handful of students took high school physics. She attributed this in part to the fear factor, math factor, and difficulty factor.

> We're not looking at a 300 level college physics class. We're looking at high school. We're looking half these kids are scared off by the thought of ever having to take physics. And some of them really like it, but some of them really don't. (Interview B, 1/17)

Tamiís awareness of studentsí fear of physics became apparent when she began to teach physics from a conceptual paradigm. Ms. White, her cooperating teacher, was very math oriented, and taught physics using problems, formulas, and equations to guide her lecture. Tami felt that physics was more relevant to studentsí lives. "But thereís also so much physics people donít recognize; thereís physics in the world" (Informal interview, 5/12). She decided to incorporate more of the conceptual aspects of physics, because she perceived that the students did not think physics or science was relevant. Tami believed that if students could she the relevance of physics, they would be less fearful of physics.

> They don't like science because they feel like it's irrelevant and that it's all theoretical and no hands-on. The one's that don't like it. And I want to change that. I want to make it relevant and hands-on. And get them involved in it. But you've got to have a lot of, you've got to have materials, you've got to have good curriculum in order to do it. (VD4).

Physics was viewed from the macroscopic perspective. Maggieís thermodynamics perspective was based upon her background in physics and mathematics. She believed that a macroscopic view of thermodynamics meant an average of all the individual molecules within a system. Maggie used the term "system" to indicate viewing science from a bigger or more inclusionary perspective. In her third analysis of vignette D, Maggie commented on the use of the term macroscopic by Mr. Jackson.

> Peter said that thermodynamics is...íit means that things are in motion, like bodies, if you know what I mean.í Besides being a halfway unintelligible sentence. Thermodynamics is not bodies in motion. It's particles in motion that give the whole macroscopic system, something to look at. (VD3)

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Maggieís strong content knowledge was one reason why she was able to explain what Peter intended in his comment. She was also able to explain that the molecular movement of all the particles represented a system.

Tamiís first response to Vignette D included a comment about kinetic energy. "With the temperature they have the same average kinetic energy. The molecules average rate is the same" (VD1). Even though she did not mention the microscopic view, she focused on the molecular level. During her third response to Vignette B and after teaching temperature and heat for a week in her physical science class, Tami was able to comment specifically on how she would teach the concept of heat energy. "What is energy? Go into the kinetic activity of it, the heat transfer. Then from there we talk about kinetic activity, molecules and stuff, oh, well, that's how we measure the temperature" (VD3). Her explanation integrated kinetic energy with heat transfer, molecular motion, and temperature. Tami had a mixed perspective of thermodynamics. While some of her comments reflected the microscopic perspective (molecular energy and molecules), others were pertinent to the macroscopic perspective (heat transfer and temperature).

During Tamiís last response to Vignette D, she circled the word macroscopic on her copy of the vignette. When asked why she circled the word, and prompted to discuss the microscopic versus the macroscopic aspect of thermodynamics, Tami replied, "The reason I circled this is because I donít know the difference...I would think micro would be more important than the macro" (VD4). Her understanding of the difference in perspectives was based upon her belief that the smaller, microscopic view of science was more difficult to use when learning about thermodynamics.

> Most people understand the macro topic. I mean they understand that yes, this gives off heat, so they don't understand the kinetic energy and the microscopic level of it. The macro is usually what we're used to. But the micro is usually what we haven't learned as well. (VD4)

Tamiís perspective on thermodynamics stemmed from her background in chemistry. She used this background in her suggestions of how to teach thermodynamics. She was cognizant of the macroscopic perspective, but only through the lens of a chemist. In a separate interview about the distinction between the microscopic and macroscopic perspectives, Maggieís cooperating teacher who had taught chemistry, physics, physical science, and geology for 25 years, stated:

> I know thereís a big difference in the two [perspectives]. The best way to explain it, I donít know if thereís a better way or not. Now again, Iím set in a certain way. If Iím in chemistry and Iím thinking along chemistry lines, if youíve ever written textbooks, because it isnít easy to solve these things. That the micro is what I would do...The reaction rates laws and things like that get placed in chemistry, but in physics, I think thereís more of a big picture of it; temperature and pressure and all that stuff. (Mr. Bently interview)

Discussion

TTF Model

Learning to teach is "an ongoing process that ideally extends throughout a teacherís career" (Borko, 1989, p. 69). Currently, there are few models for secondary teacher development (Bell & Gilbert, 1996; Cheung, 1990; Sakofs, 1995; Saunders, 1994). As part of the standards for accreditation, the National Council for Accreditation of Teacher Education (NCATE, 1994) demands that professional education programs adopt a model that explicates the purposes, processes, outcomes, and evaluation of the program. The Technical-Tactical-Functional (TTF) model in this paper warrants construction and analysis for two reasons. First, there exists a "traditional" polarization of beliefs and implementation in education. Second, current models fail to accurately address and outline the role of PCK in science teacher professional development. The current National Science Teachers Association (NSTA), NCATE, and National Science Education Standards documents support the idea of a model for teacher development (National Research Council, 1996; NSTA, 1999). In particular, science reform initiatives on the national and state level are beginning to require more rigorous standards for certification. As part of the certification process, a developmental model is needed to guide science educators through the labyrinth of knowledge bases. The results of this study support the development of a TTF Model of PCK development. The TTF Model describes how the prospective teachers viewed teaching before and during their student teaching field experience. The TTF Model represents how a prospective chemistry or physics teachers might view science teaching or content specific teaching while "learning to teach."

A technique is a skill acquired or learned through repeated actions. Skills do not have to be understood or internalized, yet they are integral parts of teaching. For example, the ability to lecture on chemical compounds could be considered technical if the teacher shows them the "cross over" trick using charges and

subscripts. In another example, Maggie lectured and introduced physics equations utilizing equation writing and variable exchange without in-depth explanations.

Tactics, on the other hand, are the processes used to achieve goals. These processes are different than the products one might associate with a task or skill. Processes involve more decision making and understanding of situations. Hence, tactical abilities are the science of achieving teaching and learning outcomes. For example, Tami realized that there was a process to teaching students how to do math when applied to physics. Tami did not learn how to explain mathematical problem solving techniques in her science education program. The process for a teacher to learn to use various mathematical techniques within the context of students understanding content is considered a tactic because it eventually led to achieving the goal of learning the concept through mathematics.

The function aspect of the model describes the specific context in which the teachers and students achieve the same goal. The context in this instance is the classroom and all of the factors which might influence the achievement of the goal. For example, Randi struggled with the purpose and reason for teaching covalent bonding of oxygen when the bonding itself was an exception to certain rules. The exceptions to the rules and corollaries in chemistry bothered Randi and Amy, but due to the context of the chemistry class (e.g., state curriculum, shortened time frame, political pressure from principal, and studentsí prior knowledge) they had to teach a prescribed curriculum about bonding. The lack of experience within the classroom and with teaching the content topic of covalent bonding also showed the slow development of functionality in teaching chemistry.

Figure 1 describes the TTF Model of PCK development as it relates to beliefs. Veal (1998) described the development of PCK as consisting of different attributes. These attributes needed to be integrated in a semi-ordered manner beginning with content and knowledge of students, and then followed by eight other attributes related to the contextual nature of teaching. The figure represents the prospective teachersí beliefs as unchanging when applied to learning techniques and content alone. Only when the prospective teachers began to realize studentsí perspectives on learning and the processes necessary to learn and teach content items, did they add additional beliefs to their already existing belief structure. When the prospective teachers began to assume all of the responsibilities of teaching during their student teaching field experience, they began to synthesize and incorporate other beliefs into their existing belief

structure. Ultimately, the incorporation, synthesis, and addition of beliefs lead the prospective science teachers to a level of teaching associated with having PCK. None of the teachers had developed a full repertoire of PCK attributes, but PCK development had begun. Teaching was deemed a life long process by the participants, thus the synthesis and development of PCK and beliefs can be determined as a life long process.

Figure 1. The TTF Model of PCK development using beliefs as an indicator of development.

Effects of Beliefs on PCK Development

Technique required no use or application of a belief to a situation. Tactics required the modification or implementation of an existing belief while developing new beliefs. Function described the synthesis of competing or differing beliefs into a context in which a new or temporary belief existed for the purpose of teaching and learning. Beliefs and PCK were inextricably intertwined. Beliefs informed the practice of the participants in the classroom, and knowledge gained in the classroom informed the participantsí beliefs. It was determined that there was a synergistic relationship between the beliefs and knowledge as a result of being in a social milieu (Tobin, Tippins, & Gallard, 1994). The synergistic relationship between beliefs and PCK created a unified understanding, rather than a divergent comparison between them. There exists little distinction between beliefs and knowledge (Kaggan, 1990). On the other hand, some researchers distinguished between beliefs and knowledge based upon the "potent affective, evaluative," and "episodic nature of beliefs makes them a filter through which new phenomena are interpreted" (Pajares, 1992, p. 325; See also Grossman, Wilson, & Shulman, 1989; Nisbett & Ross, 1980).

Several conclusions based upon the data are presented to inform the notion that beliefs and PCK development are inextricably tied together. Whether the link is a common knowledge base or whether one informs the development or change of the other is not as significant as the idea that beliefs and PCK development is synergistic. First, a "conceptual change" in beliefs did not fully occur in these participants. The participants may have realized or understood new ideas about teaching science, but there was not a complete change (Ranney, 1987). Based upon their teaching observations, the participantsí actions did not always equate with what they believed was the ideal model for teaching. The participantsí prior beliefs and understandings about content topics (such as oxygen bonding,

ideal gas law, and corollaries) impeded their development of new belief systems which incorporated more diverse beliefs. Ultimately, this did not translate fully into action.

Second, prospective teachers had difficulty developing PCK and altering existing belief structures when the content was deemed magical, abstract, or too mathematically oriented. Libby (1995) described the use of a Piaget-based learning cycle technique for teaching an introductory organic chemistry course. The step-by-step learning cycle provided the students with concrete examples to aid in understanding abstract concepts. In a separate study, Seymour and Longden (1991) reported that students in the formal operational level could understand the abstract concepts of gas exchange and respiration, whereas those students at the concrete operational level could not. Zeitoun (1988) concluded that prior knowledge and formal reasoning played a major role in studentsí achievement of abstract concepts, and that this achievement seems to exceed that of formal reasoning. This conclusion can also be applied to prospective teachers, in that prospective teachers rely on how they were taught a subject as the basis for their instruction.

In order to develop PCK, prospective teachers had to change their beliefs, sometimes based on misconceptions they had learned as students. Part of this disparity between learning and implementing is the correct usage of appropriate and definitive language. Whether the participant was teaching concepts on heat, temperature, or conservation of matter, there was a translational impediment of understanding for the student as well as for the instructor. The prospective teachers did not always translate their personal beliefs into practice. Shulman (1987) stated that PCK was "the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (p. 8.).

Third, the prospective teachersí instruction was perceived as coming from a learnerís perspective. Rather than adjusting their beliefs to incorporate more of the experiences from student teaching, the prospective teachers had difficulty translating their conceptions of content from when they were a student into meaningful teachable moments. For example, many of the chemistry content items learned by the prospective chemistry teachers as magical were not fully understood as concrete concepts. These concepts were not forced to be concrete until the prospective teachers had to teach the concepts to the students. Amy stated that the ideal gas law was really not ideal because it had exceptions or corollaries. She struggled with the idea of teaching the equation

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knowing that it wasnít true as stated or introducing the students from the start that gases did not behave in a real manner.

Categories on Beliefs and PCK Development

Chemistry as magical

Some elementary science textbooks or articles present science as magical (e.g., Guerra, 1988; McCormick, 1979; Struass, 1997; Woolley, 1997). Other articles suggest that chemistry concepts can be demonstrated using magic as the vehicle of dissemination (Battino, et. al, 1995; Berry, 1989; Bindel, 1996). Even though some articles suggest the use of magic in science, other articles advise teachers to use cautionary practices when discussing science content when students perceive phenomena as magical (Woolley, 1997). If teachers are aware of the possible problems associated with the distinction between science and magic, then magic could effectively be used as an engagement activity (Hague, 1983; Smith, 1986). The problem discovered with these prospective teachers was that they did not know how to alter their belief structure about content items so that the content was presentable for student learning.

Abstract

In order for the prospective teachers to make the content more concrete, they developed some practical and applicable activities for their students. This conclusion is supported by the literature on abstract science learning (Bates, 1975; Larson, 1997; Libby, 1995; Lock, 1997; Simms & Leonard, 1986; Springer, 1997). The literature supports the idea that abstract concepts need to be grounded in concrete examples for better conceptualization and understanding. Even though most of the participants believed that they would teach science in a concrete and applicable manner, their classroom actions did not equate. This was do to their struggle with learning the contextual aspects of science teaching and trying to accommodate new beliefs with their existing belief structure.

Difficulty of Physics

Physics has always been perceived as the most difficult subject to take in high school. This is one reason why it is often the last class in the science sequence. Several research papers have concluded that physics is a difficult subject as perceived by teachers and students (Chia, 1995; Jonas, 1992; Okpala & Onocha, 1988; Rowe, 1975; Sprung, 1973). For example, Rowe (1975)

suggested that tough grading practices, lecturing, and a lack of a methodology in teaching abstract concepts were reasons for the low popularity of physics. In terms of the physics prospective teachers, they knew physics was a difficult subject and attempted to alter their instructional process to include concrete, applicable, and hands-on activities and ideas.

Mathematical Aspect of Physics

The prior mathematical and physics experiences of both physics participants influenced how they perceived teaching physics. Both of them believed that math was the basis of physics instruction. The actual manner in which the instruction was carried out differed between the participants. Laurence (1974) reported that 30% of students who did not enroll in physics gave as a reason the mathematics aspect of the course. In this study, the prospective physics teachers combined math and hands-on, real life activities in their instruction. Although, each one did so for different reasons. Maggie used her math and physics backgrounds as a foundation for teaching. Tamiís cooperating teacher with her mathematical background influenced how Tami taught physics.

Macro- and Microscopic Perspective of Thermodynamics

Magnusson, Borko, and Krajcik (1994) developed frameworks describing content-specific knowledge which they suggested could be useful to conceptually frame analyses. The frameworks were created to describe how their participants (middle school physical science teachers) viewed thermodynamics. Magnusson et al.ís (1994) two frameworks for analyzing content-specific knowledge of science teachers were Microscopic and Macroscopic. The Microscopic Framework was associated with molecular motion and heat energy, and the Macroscopic Framework was associated with energy systems. The Macroscopic Framework had three sub frameworks that teachers in the study used to view heat and temperature concepts: Factor, Energy, and Transfer. Randi and Tami discussed and approached the teaching of thermodynamics from a Microscopic Framework. Amy, on the other hand, viewed teaching thermodynamics from an Energy Framework during the curriculum class, and switched to the Transfer Framework during her student teaching field experience. Magnusson, et al. (1994) defined the Energy Framework as the heat energy of the whole system, and temperature as the energy of the part. Even though the Energy Framework was incorrect in relation to content, some of the middle school teachers in Magnussonís study used this to view thermodynamics concepts. Magnusson, et al. (1994) also defined the Transfer Framework as heat energy being the energy associated

with a change in the temperature (a correct statement in relation to content). The development and use of a framework, perspective, or orientation, based upon beliefs, in "learning to teach" a domain of science could help a prospective teacher develop PCK (DeRuiter, 1991).

Other papers have described thermodynamics from a micro- and macroscopic perspective. For example, a science project in Portland used the unifying concept of energy as the bond for an integrated curriculum. The macroscopic aspects of heat as embodied in calorimetry were related to the microscopic in terms of random molecular motion. Ericson (1988) described an apparatus capable of demonstrating the concept that temperature is related to the micro- and macroscopic world. On the other hand some articles in physics have focused on the microscopic aspect of thermal conductivity (e.g., Allen, 1983). There is no one way of accurately viewing heat and temperature within thermodynamics. In essence, chemists view thermodynamics more from a microscopic view and physicists from a macroscopic view. In relation to prospective teachers, they do not have enough experience and content knowledge to understand fully the distinction between the macro and microscopic perspectives.

Conclusion

The TTF model was constructed from the perspective teachersí activities, models, ideas, examples, and laboratories used during their student teaching experience. It was also constructed with the prospective teachersí belief system about science teaching. For example, data from vignette responses illustrated the macro- and microscopic viewpoints of physics and chemistry respectively. The prospective teachers showed little differentiation to these perceived content-specific viewpoints. In another example, actual experience in the classrooms and interacting with students created dissonance in the prospective teachersí beliefs about their subject matter. Thus, the prospective teachers learned that chemistry and physics could be viewed from different viewpoints. These viewpoints often conflicted with their prior beliefs about content and teaching. Their subsequent teaching reflected PCK growth within the TTF Model and in "learning to teach."

The findings support a view of secondary science teacher preparation as consisting of an interaction between beliefs and the development of a knowledge base for teaching. Teachers ground their development of a knowledge base in their existing beliefs. This ultimately effects how they teach in the classroom. If so, prospective teachers could develop their PCK by making

their epistemology explicit and by learning from and studying about other more experienced teachers. In order to help PCK development, prospective teachers need to reflect on their beliefs about epistemology and the corresponding applications. Development is a slow and gradual process that relies on one changing his/her existing belief structure to accommodate new beliefs. Teacher education programs need to provide a meaningful and alternative perspective to the empiricism that is predominant in most teacher education programs (DeRuiter, 1991).

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